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A morphodynamic model of atoll-islet evolution

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A Morphodynamic Model of Atoll-islet Evolution

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Certification

I, Stephen J. Barry, declare that this thesis, submitted in fulfillment of the requirements for the award of Doctor of Philosophy, in the School of Earth and Environmental Sciences, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Stephen J. Barry

Date:

"There are two kinds of truths: those of reasoning and those of fact"

Gottfried Wilhelm Leibniz

"All models are wrong, but some are useful"

George E. P. Box

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a	height at the transect origin.
b	sediment transport impedance term. The linear parameter in the logistic function representing transport gradients relevant to sediment sequestration by the island.
c	$\ln(h/a)L$.
D	a *Sloss* variable; the dispersal factor.
i	increment counter.
$1\text{-}f(v/V_{max})$	island sediment sequestration ratio. The proportion of available sediment sequestered by the reef-island.
$f(v/V_{max})$	the proportion of available sediment that bypasses the reef-island.
*f*1*_error*	$1\text{-}f(v/V_{max})$ when $v/V_{max} = 1$. When the accommodation volume is filled no sediment is sequestered by the island. This means that, ideally, the value of $1\text{-} f(1) = 0$, however, since $0 < f(v/V_{max}) < 1$, this will never be the case. Instead, the *f*1*_error* can be used as an error term in the nonlinear optimization routine.
h	ridge height.
L	length measurement.
m	meter.
p	the perturbation amount calculated as $p = \tilde{v}(i) \times p_{max} \times x$. This value was used to perturb the exact value, $\tilde{v}(i)$, during testing of the inversion procedure. For example, if $\tilde{v}(i) = 100$, $p_{max} = 0.1$, and $x = -0.5$, then $p = 100 \times 0.1 \times -0.5 = -5$, then the value of $\tilde{v}(i)$ used in the parameter recovery process is $\tilde{v}(i) = \tilde{v}(i)$ - -5 =100 + 5 = 105.

p_{max}	the maximum perturbation ratio. If the measured value was 100 and the maximum perturbation ratio was 0.1, then, the maximum absolute value of the perturbation is $100 \times 0.1 = 10$.
Q	a *Sloss* variable; the quantity of sediment available for deposition.
r	transport-impedance sensitivity to morphology. The nonlinear parameter in the logistic function that represents morphodynamic feedback parameter, i.e. the response of sediment transport processes to island growth.
R	a *Sloss* variable; the accommodation available for sediment deposition.
s	rate of sediment production; seconds.
s_i	sediment produced during step *i* of the forward model.
t	time.
t_0	$t = 0$.
$\tilde{v}$	vector of island volume measurements.
v_0	initial volume of the island at $t = 0$. In the solution to the logistic equation $b = (1/t_0) - 1$, therefore $t_0 \neq 0$, and $v_0 \neq 0$. This implies that the island forms as the result of a pre-existing perturbation of the sediment transport field. For the purposes of testing it was assumed that the initial island volume was 0 m^3.
$\tilde{v}'$	vector of island volumes calculated using the forward model.
V_{max}	accommodation volume, the maximum volume available for island development.
$w()$	weighting function. This is used to magnify the *f*1*_error* value so that it is significant when compared to the calculated error term in the optimization process.

x	unit of length; a random number in the range [-1, 1].
y	unit of length.
yr	year.

List of Abbreviations

ECD	Effective conglomerate distance
ENSO	El Niño Southern Oscillation
GIS	Geographic Information System
IQR	Interquartile range
LD	Lagoonside deposition
OD	Oceanside deposition
SAM	Sediment Allocation Model
SLR	Sea-level rise
VBA	Visual BASIC for Applications

List of Publications

Barry, S.J., Cowell, P.J. and Woodroffe, C.D., 2007. A morphodynamic model of reef-islet development on atolls. Sedimentary Geology, 197(1-2): 47-63.

Barry, S.J., Cowell, P.J. and Woodroffe, C.D., 2008. Growth-limiting size of atoll-islets: Morphodynamics in nature. Marine Geology, 247(3-4): 159-177.

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Abstract

A morphodynamic model of atoll-islet evolution, the Sediment Allocation Model (SAM), was developed based on the assumption that islets are equilibrium landforms. The assumption that islets are equilibrium landforms implies that the volume of sediment sequestered in an islet reaches stability when considered over the time-scale of islet evolution. Stability of the islet implies that the maximum volume of an islet (accommodation) can be quantified. Morphodynamic feedback between the islet and sediment transport processes is manifest in the rate of sediment sequestration by the islet. Initial increase of islet volume is rapid, sediment sequestration slows as islet volume increases, and stops when accommodation is full.

The rate of islet development is constrained by antecedent morphology, sediment supply, and sediment transport. The constraints and accommodation for islet evolution are difficult to measure directly. Estimates of the accommodation, sediment supply, the effect of antecedent morphology, and the morphodynamic feedback between islet volume and sediment sequestration are generated using measurements of islet volume in an inversion algorithm. Experimentation carried out using a hypothetical test-case indicated that errors in the measurements of islet volume used in the inversion algorithm would result in a damping of the morphodynamic feedback and overestimation of both sediment supply and accommodation.

The SAM was implemented using published radiocarbon-dated samples for surveyed islets transects. A data-model template was developed to incorporate the published data into the SAM. In the data-model template an atoll-islet was represented by a

combination of morphological sub-units with sub-unit sequestration dominated by either lagoon processes or ocean processes. The input to the SAM was a series of sediment volumes representing islet evolution. Sediment volumes were calculated using isochron patterns that represent a hybrid of lateral accretion and vertical accretion, recognized modes of sediment accumulation on atoll-islets. Sediment volume measurements calculated using the hybrid-accretion patterns were consistent with the assumption of morphodynamic feedback between islet morphology and sediment accretion processes.

Comparative metrics are required to test and refine models of islet evolution, however, suitable comparative data are not currently available. The hybrid-accretion pattern of islet evolution formed the basis for the development of a metric to determine islet location on the reef platform. Islet location was measured on four atolls as the distance from the reef crest to the oceanward beach-toe. The results of the measurement procedure were evaluated in the context of three factors that influence islet evolution: energy-exposure, sediment supply, and antecedent morphology. The results indicate that the distance from the reef crest to the oceanward beach-toe is a measurable response to the influence of the three factors.